

The construction and commissioning of the CMS Silicon Strip Tracker

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As the start up date for LHC approaches, the detectors are readying for data taking. Here a review will be given on the construction phase with insights into the various difficulties encountered during the process. An overview will also be given of the commissioning strategy and results obtained so far.

The CMS tracker is the largest silicon microstrip detector ever built. Consisting of three main subsystems, Inner Barrel and Disks, Outer Barrel and End Caps, it is 5.4 m long and is 2.4 m in diameter. Total detector surface is an unprecedented 200 m² with more than 15000 detector modules.

The various integration procedures and quality checks implemented are briefly reviewed. Finally an overview is given of checkout procedures performed at CERN, after the final underground installation of the detector.

1. CONSTRUCTION AND INSTALLATION

The CMS Silicon Strip Tracker (SST) is the world's largest Silicon strip detector with a volume of approximately 23 m³ instrumented by 15 148 modules for a total of 198 m² of Silicon active area and 9 316 352 channels with full optical analog readout [1, 2]. The SST, shown in Figure 1, covers the radial range between 20 cm and 110 cm around the LHC interaction point. The barrel region ($|z| < 110$ cm) is split into a Tracker Inner Barrel (TIB) made of four detector layers, and a Tracker Outer Barrel (TOB) made of six detector layers. The TIB is complemented by three Tracker Inner Disks per side (TID). The forward and backward regions ($120 \text{ cm} < |z| < 280 \text{ cm}$) are covered by nine Tracker End-Cap (TEC) disks per side. In some of the layers and in the innermost rings, special stereo modules (Fig. 1, right panel) are used to build double sided assemblies able to provide three-dimensional position measurement of the charged particle hits.

The SST is made up of relatively small carbon fiber assemblies supporting several modules to ease the handling and the mounting. These substructures are fully equipped with cooling and readout electronics to allow for stand-alone tests to be performed. This modularity has been the key-factor for the successful assembly of the huge number of Si-strip modules [3] and all other ancillary components into the final detector. The following subdetector-dependent substructures can be found in the SST (Fig. 2): the TIB is split into 16 half cylinder *shells* each holding 135 to 216 modules; the TID is structured in 3 *rings* per disk, each designed to support 40 or 48 modules; the TOB is made of 688 *rods*, drawer-like structures providing support for 6 or 12 modules; and the TECs are made up of 144 *petals* per endcap, each holding 17 to 28 modules. During each stage of the assembly, every single component is verified.

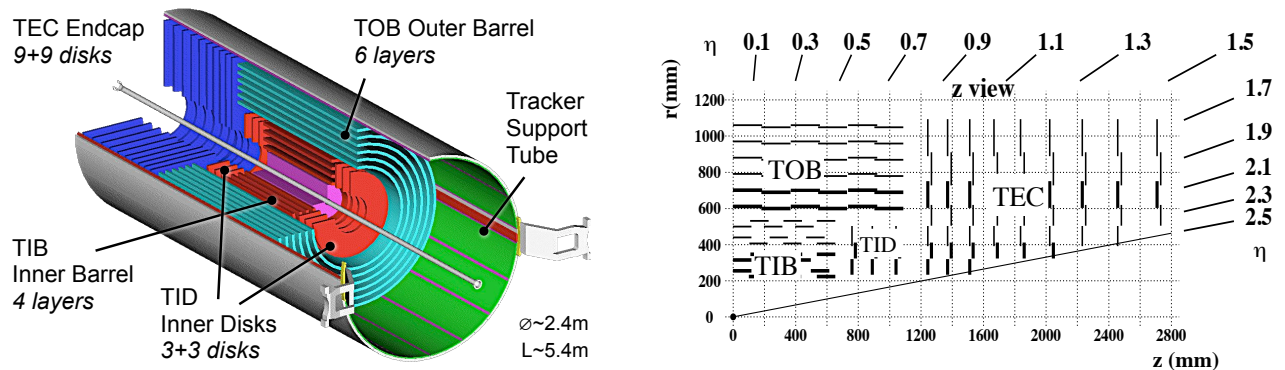


Figure 1: The CMS SST: simplified view (left panel); a quadrant of the rz section (right panel, bold lines represent double sided module assemblies).

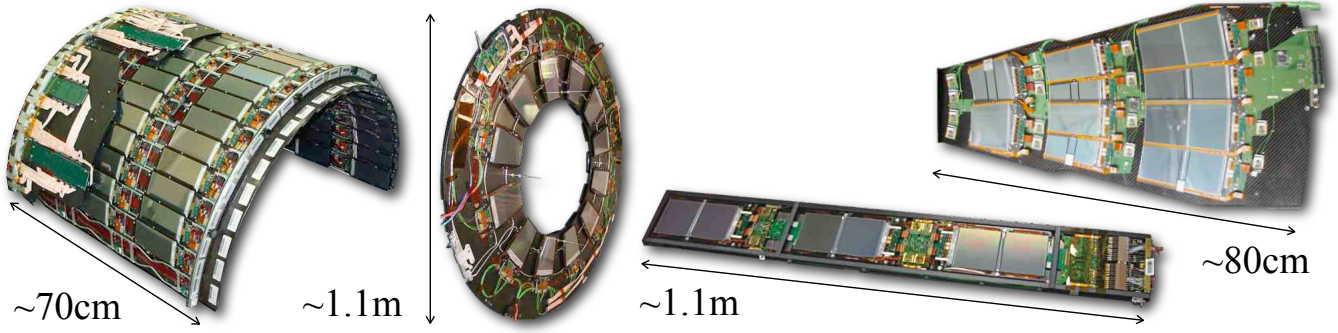


Figure 2: From left to right: a shell of the TIB; the innermost ring of a TID disk; a rod of the TOB; a petal of the TEC.

Optical links are checked by measuring the output level of an auxiliary signal issued by the readout chips and modules are checked using pedestal and noise data at full bias (400 V) to spot high voltage issues and bad channels [4, 5]. Once the substructures were completed, system-wide tests were performed for which cooling was provided as in final CMS operating conditions. Temperature probes mounted on the modules are effective for identifying cooling circuit problems [6]. In many cases, a cosmic ray setup was implemented to measure the S/N ratio for MIPs and to perform track reconstruction exercises, so to verify the overall mechanical precision at the sub-millimeter level.

During 2006 all substructures were assembled to create the main subsystems in regional integration centers. Finally the tracker subsystems were installed in the Tracker Support Tube at the CERN Tracker Integration Facility (TIF) between fall '06 and March '07. The tracker quality was excellent. The total fraction of bad channels was found to be 0.21%: 0.07% due to module failures, 0.05% due to bad optical links and 0.09% of bad isolated channels, mostly preexisting problems. The assembly procedures and the stringent quality control tests have been proved to be sound as the integration process caused almost no new defects.

Once the assembly of the SST was complete, it was possible to evaluate the material budget by introducing into the detector simulation all the last-minute details added during the construction. The total thickness as a function of η reaches a maximum of about $1.8X_0$ around $1.2 \lesssim |\eta| \lesssim 1.8$ (Fig. 3). This is because of the presence of TIB and TID services in this region, which contribute significantly to the overall material budget. TIB and TID are the most challenging subsystems in terms of volumetric density of channels (in units of 10^6 channels per m^3 : TIB 2.2, TID 1.1, TOB 0.52, TEC 0.35) yielding a very large number of service connections in a very small space. This resulted in the previously discussed material budget issue and in difficulties to integrate the services in the limited room allocated.

In December '07 the SST was installed underground in CMS and the full cabling and piping was completed in

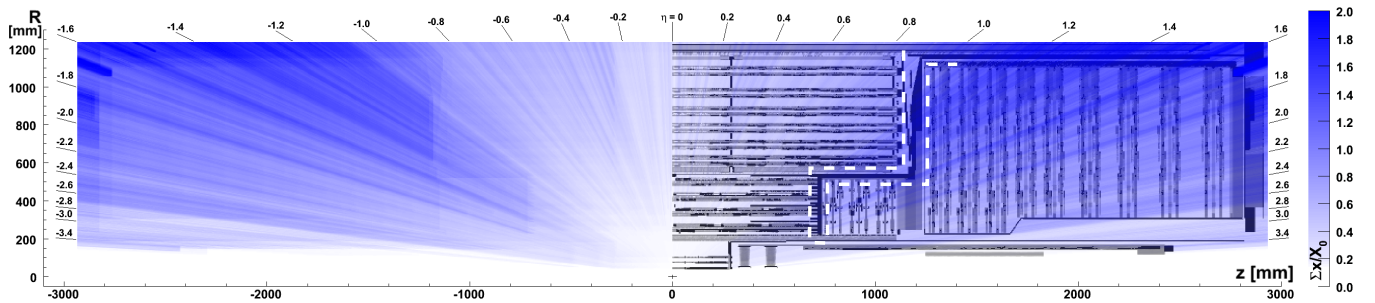


Figure 3: Material budget rz map as seen by straight tracks originating at the interaction point: blue tone represents average of total upstream x/X_0 (i.e. local density of photon conversion tracks); gray tones (shown only on the $z > 0$ part) represents average of $1/X_0$ (i.e. local normalized density of photon conversion vertexes). The white dashed line indicates the region where TIB/TID services are deployed.

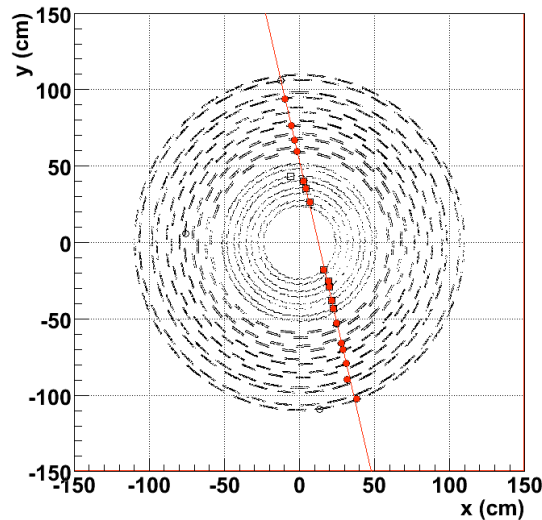


Figure 4: A reconstructed cosmic muon track passing through the SST collected during the Global Cosmic Run.

March '08. Unfortunately two serious hardware failures of the cooling system serving the tracker (November '07 and May '08) prevented the checkout activities from being performed as scheduled, i.e., immediately after the installation. The entire cooling system needed to be refurbished and was available in June '08. In the 2008 LHC run, the SST will be conservatively operated at about $+12^{\circ}\text{C}$ instead of at the design temperature of -10°C ; in any case, the latter is only required at design luminosity. During the 2008/2009 LHC shutdown the cooling system will be commissioned for cold operations.

2. COMMISSIONING

Immediately after the finalization of the assembly at the TIF, an extensive testing program known as the “Slice Test” was carried out. It consisted of cooling, powering and reading out approximately 15% of the entire SST. A scintillator-based trigger permitted 5 million cosmic muon events to be collected at a rate of about 5Hz, filtering out low momentum muons by means of a 5 cm-thick lead shield placed on the bottom scintillator. The Slice Test allowed the first experience to be gained on commissioning, safety, controls, monitoring, data management, track reconstruction and alignment [7].

After the installation within CMS and once the cooling system was available, the SST joined CMS operations. A cosmic global run without magnetic field took place from 7 to 14 July '08. The test was very important for CMS: the SST readout makes up approximately 70% of the entire DAQ system. Despite the tight schedule for the first round of commissioning, the SST performance is remarkable. The SST was smoothly read out within the global CMS DAQ and several million events were collected. 79% of the SST modules were switched on (technical issues prevented the endcap on the $-z$ side from being used) and, of those, around 93% passed the testing procedures first time. The vast majority of the small number of modules excluded from this first global run will be simple to recover. In fact, the following subsequent more detailed commissioning performed before the closure of CMS in fall '08, certified that the fraction of bad modules in the entire SST is below 1%.

Cosmic muon tracks have been observed in the global run: an example is shown in Figure 4.

3. CALIBRATION HIGHLIGHTS

The optimization of the SST depends on several calibration steps [7]. The most relevant are briefly described here.

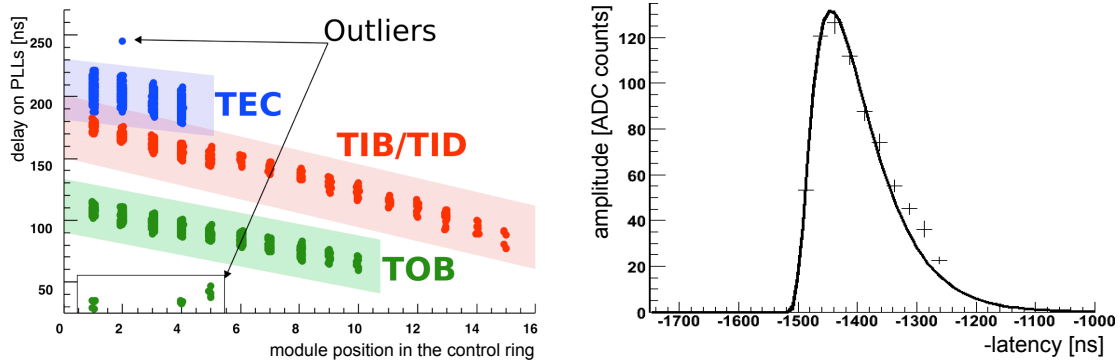


Figure 5: The delays set on the modules programmable delay units against the module position within the control ring (left panel); CR-RC pulse shape reconstructed by scanning on the latency values (right panel).

The SST dimensions and cable/fiber lengths imply non negligible timing differences compared to the LHC bunch-crossing period and the detector shaping time. Each module needs to be synchronized to compensate for path differences of control signals (and for any electronics delay) as shown in Figure 5, left panel, where the delays set on the programmable delay unit of each module is plotted against the number of upstream controller chips. In fact, to limit the number of optical links, the control circuit is implemented by daisy-chaining several controller chips introducing a delay that needs to be compensated for.

The analogue signal optimization is another fundamental calibration step, to be obtained by setting up the working point parameters of the front-end chips and the downstream optical chain. Among these, one of the most important is the configuration of the front-end chips with the appropriate *latency* value that, once a L1 trigger is issued, makes each module send the data samples corresponding to the correct bunch crossing to the FEDs (the SST ADC boards). The result of the corresponding procedure (*latency scan*) are shown in Figure 5, right panel: the CR-RC pulse shape is reconstructed by scanning a range of possible latency values in steps of 25 ns and taking as the optimal setting the closest value to the maximum amplitude. In addition a fine tuning within a single bunch crossing will compensate for time-of-flight effects [8].

4. CONCLUSIONS

The SST has been built, installed and read out within CMS. Commissioning procedures, online and offline tasks have been demonstrated to work well. Final commissioning and checkout procedures have demonstrated that the SST quality is excellent with more than 99% of good modules. The SST is ready to deliver optimally reconstructed tracks.

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